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ASSESSING THE INFLUENCE OF FLOATING CONSTRUCTIONS ON WATER QUALITY AND ECOLOGY

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Large floating projects have the potential to overcome the challenge of land scarcity in urban areas and offer opportunities for energy and food production, or even for creating sustainable living environments. However, they influence the physical, chemical, biological and ecological characteristics of water bodies. The interaction of the floating platforms affect multiple complex aquatic processes, and the potential (negative/positive) effects are not yet fully understood. Managing entities currently struggle with lack of data and knowledge that can support adequate legislation to regulate future projects. In the Netherlands the development of small scale floating projects is already present for some years (e.g. floating houses, restaurants, houseboats), and more recently several large scale floating photovoltaic plants (FPV) have been realized. Several floating constructions in the Netherlands were considered as case-studies for a data-collection campaign. To obtain data and images from underneath floating buildings, underwater drones were equipped with cameras and sensors. The drones were used in multiple locations to scan for differences in concentrations of basic water quality parameters (e.g. dissolved oxygen, electrical conductivity, algae, light intensity) from underneath/near the floating structures, which were then compared with data from locations far from the influence of the buildings. Continuous data was also collected over several days using multi-parameter water quality sensors permanently installed under floating structures. Results show some differences in concentrations of water quality parameters between open water and shaded areas were detected, and some interesting relations between parameters and local characteristics were identified. Recommendations are given, in order to minimise the undesired impacts of floating platforms. Considering the complexity of the interactions between water quality parameters and the influence of the surrounding environment it is recommended to continue and to improve the monitoring campaign (e.g. include new parameters).

Keywords Water Quality · Ecology · Environmental Impacts · Floating structures · Monitoring tools · Aquatic drones

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1 Introduction

Floating developments are promising climate change adaption solutions, as they offer flood proof constructions and opportunities for creating sustainable living environments or for energy and food production. Floating structures influence the physical, chemical, biological and ecological characteristics of water bodies. The interaction of the floating platforms affect multiple complex aquatic processes, and the potential (negative/positive) effects are not yet fully understood. This lack of knowledge about their impact on the water quality and ecology often hinders their implementation, as water boards and municipalities often encounter difficulties and challenges for their regulation and licensing.

Floating houses block the incident short wave solar radiation, depending on their size and the sun's position [1]. This shade effect impedes the growth of phytoplankton and macrophytes below the platform [2] and hence photosynthesis is reduced. As a floating house is a barrier for wind and waves, the re-aeration of the water body is weakened on the lee side. Between two houses a tunnel effect may occur at higher wind velocities causing better mixing of the water column [3]. The surfaces of platforms get colonized by sessile organisms [4] which use oxygen for respiration and therefore may deplete the dissolved oxygen content of the surrounding water. Excreted nutrients get dispersed increasing the nutrient concentration in the water as well as at the water bottom. Dead mussels also fall down and get decomposed, which may increase the oxygen demand at the water-sediment interface [5,1]. Kitazawa et al. (2010 [5]) reports that no decrease in current velocity nor variations in temperature and salinity were observed; however, the concentration of dissolved oxygen was slightly lower in the deeper column below the platform, but did not reach hypoxic or anoxic levels, not even in summer. Foka (2014 [3]) detected a reduction of dissolved oxygen by 1mg/l between two floating houses, compared to open water. These differences occurred only in the upper layers (<1m depth) and mainly around noon, whereas in the morning and evening at both sites similar values were recorded. For water temperature the difference was 0.5K, temperature variations in depth were very small. Hartwich (2016 [1]) and de Lima et al. (2015a [7], 2015b [8]) found that oxygen content decreased with greater depth, stronger than in open water. Also organic enrichment, higher nitrogen and organic carbon content was determined, in comparison to open water.

Despite these studies, managing entities currently struggle with lack of data and knowledge that can support adequate legislation to regulate future projects, and therefore further monitoring and studies are necessary. In the Netherlands the development of small scale floating projects is already present for some years (e.g. floating houses, restaurants, houseboats), and more recently several large scale floating photovoltaic plants (FPV) have been realized.

2 Methodology

To obtain data and images from underneath floating buildings, underwater drones were equipped with cameras and sensors (Figure 2; [8]). The mobile drones were used as platforms to position the sensors underneath the floating objects. Sensors were able to monitor basic water quality parameters (e.g. dissolved oxygen, electrical conductivity, nutrients and algae/chlorophyll-a) from underneath/near the floating structures, which were then compared with data from locations far from the influence of the buildings (Figure 1). As some of the sensors take time to adjust to local conditions, the drones were kept in each position for several minutes.

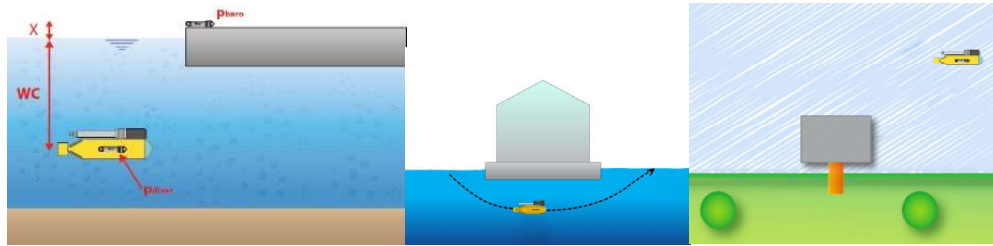


Fig. 1 Illustration of the position of underwater drones when collecting data a) near (*left*), b) under (*center*), and c) far away (>8m) of floating structures (*right*)



Fig. 2 Impression of underwater drones and sensors used in this research.

Several floating constructions in the Netherlands were considered as case-studies for a data-collection campaign. Table 1 provides an overview of these locations, including some characteristics of the structures and of the water body. This methodology was repeated in multiple locations around the Netherlands (Table 1; Figure 3), during spring/summer period.

Table 1 Information regarding the locations with floating structures in The Netherlands where measurements were collected

Name	ID	Location	Type	Year	Size (m ²)	Water system
Drijvende Kas	Naald	Naaldwijk	Greenhouse	2005	900	Pond/Storage
Warande	Lely	Lelystad	Houses	2012	800	Canal (dredged/widened)
Harnaschpolder	Harn	Delft, Harnaschpolder	Houses	2013	540	Pond/polder
Expo SeaLife Almere	Alm	Almere	Housing complex	2010	500	Harbour
Havenpaviljoen Schiedam	Sch	Schiedam	Support Pavilion	2009	64	Cana (urban)
Sea Palace, Chinese	SPAmS	Amsterdam	Restaurant	1984	900	Harbour (urban)
Zwaneneiland (Woldmeer)	Meer	Groningen, Meerstad	Houses	2013	390	Lake
Oolderhuuske Marina's	Roer	Roermond	Houses	1998	5760	Lake
Maasvillas	OeL	Ohé en Laak	Houses	2010	618	Lake (connected to river)
Gouden Wok	GW	Rotterdam	Restaurant	N/A	1700	Harbour (urban)
Floating Pavilion	FP	Rotterdam, Floating Pavilion	Pavilion for events; Expo	2010	1600	Harbour (urban)



Figure 3 Impression of some of the floating structures visited (Restaurants, floating houses, pavilions and green-houses).

3 Results

The measurement campaigns generated data that can be represented as indicated in Figure 4. This figure compares the data from open water (two graphs on the left) with the data from underneath the structure (two graphs on the right), in a single location (Floating Pavilion, Rotterdam). It can be observed that dissolved oxygen is lower under the structure than it is in open water. However, the difference is small, and above the minimum of 5 mg/L of dissolved oxygen (never lower than 7,5 mg/L). The variation of temperature seems to be mainly affected by water depth, considering that the same pattern occurs in open water conditions. As for nitrate and ammonium, on the graphs it can be seen that the concentration of ammonium increases as the drone goes deeper, while nitrate concentrations decrease.

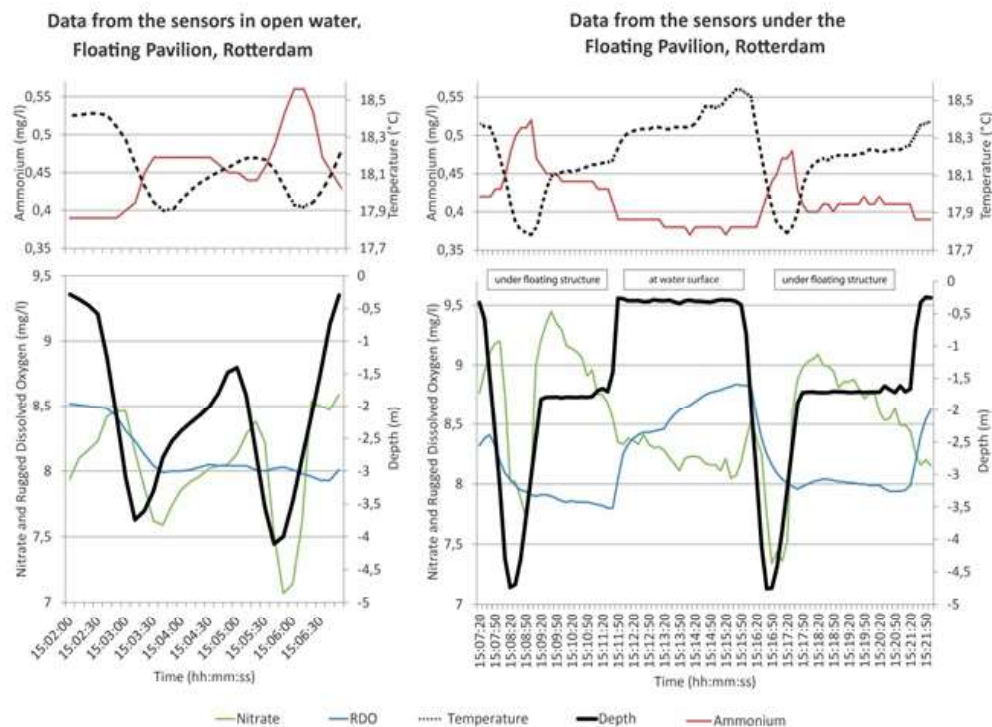


Figure 4 Plotting of various parameters in open water and under the Floating Pavilion.

Each point in Figure 5 corresponds to the averaged value of dissolved oxygen in open water (y-axis) and under/near the floating structures (x-axis), for all the measured data (at different water depths). A linear regression of this data (Figure 5a) places the fitting line slightly above the 1:1 line indicating that the differences in the dissolved oxygen values (lower under/near the house) is small. In Figure 14, the different colours correspond to different locations, whereas in Figure 5b the colour gradient relates to the depth interval.

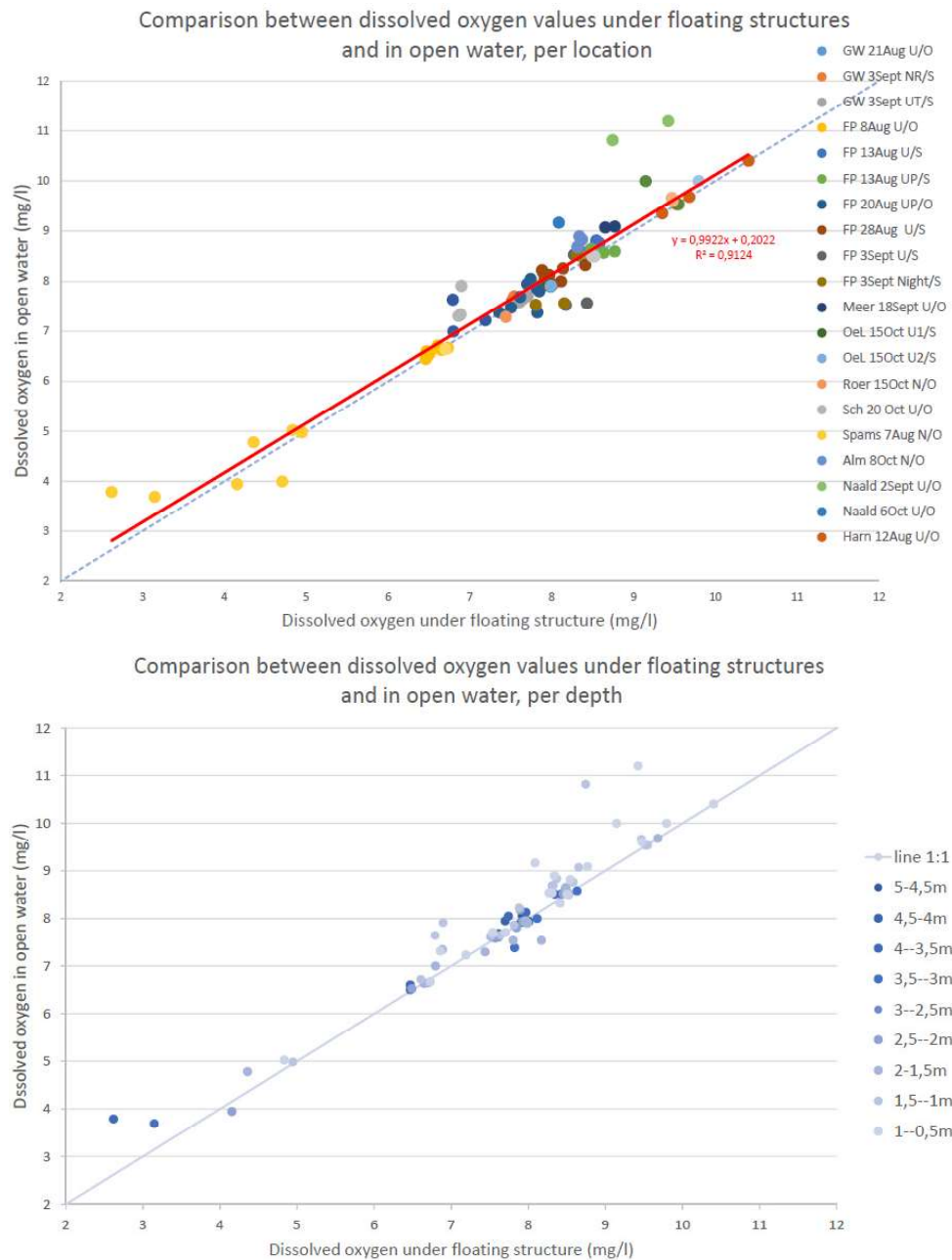


Figure 5 Comparison between dissolved oxygen values under floating structures and in open water: a) per location (top), and b) per depth (bottom)

Figure 6 shows a compilation of the measured differences data, organized in a circular graph with sections corresponding to the water depth of the measurements. This reveals that the bigger differences were detected in lower water depths (closer to the bottom surface of the floating construction), whereas for depths higher than 1,5 – 2m there isn't a noticeable difference in dissolved oxygen, in most locations. However, there is also more data available from lower depths, because when the underwater drone was collecting data under the floating constructions, it was usually positioned right under it (drone is positively buoyant). It was noticeable that locations with greater water depth

under floating structures show lower differences in the amount of dissolved oxygen when compared to more shallow locations. It is likely that the greater the depth of water below floating structures, as well as its position (near the shore, or in deeper parts of the water body) influence water mixing and water flow/currents underneath the structure, and therefore lower the amount of time for renewal of water under the houses, hence having an effect on the amount of dissolved oxygen.

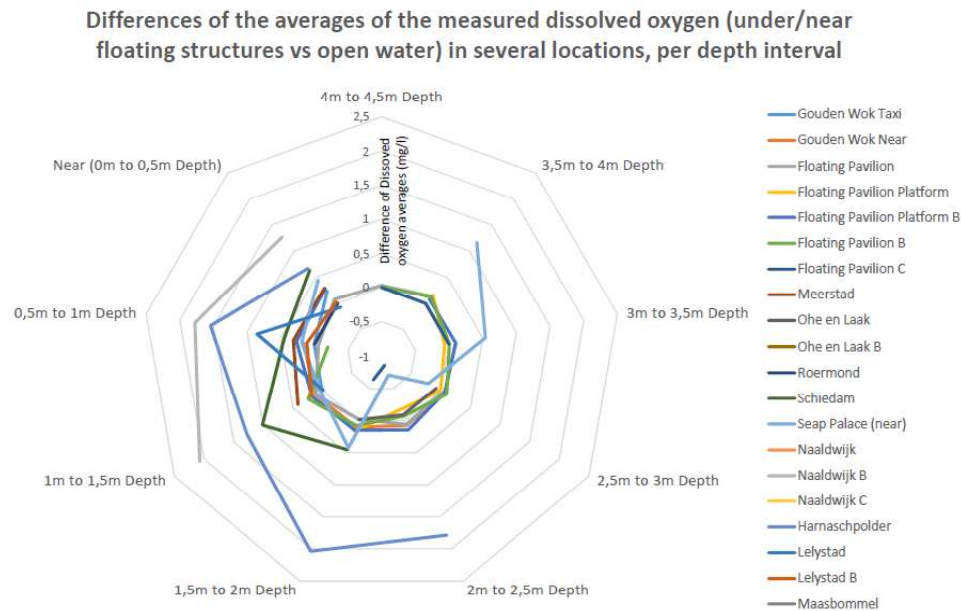


Figure 6 Differences in dissolved oxygen concentration between open water and underneath structures in several locations per depth interval.

With regard to the size of the floating structure, it was not possible to establish strong correlation as represented on Figure 7. Different platform did not result in higher differences in concentrations, which were detected in both large and smaller platforms. The same was observed for lower differences in concentrations.

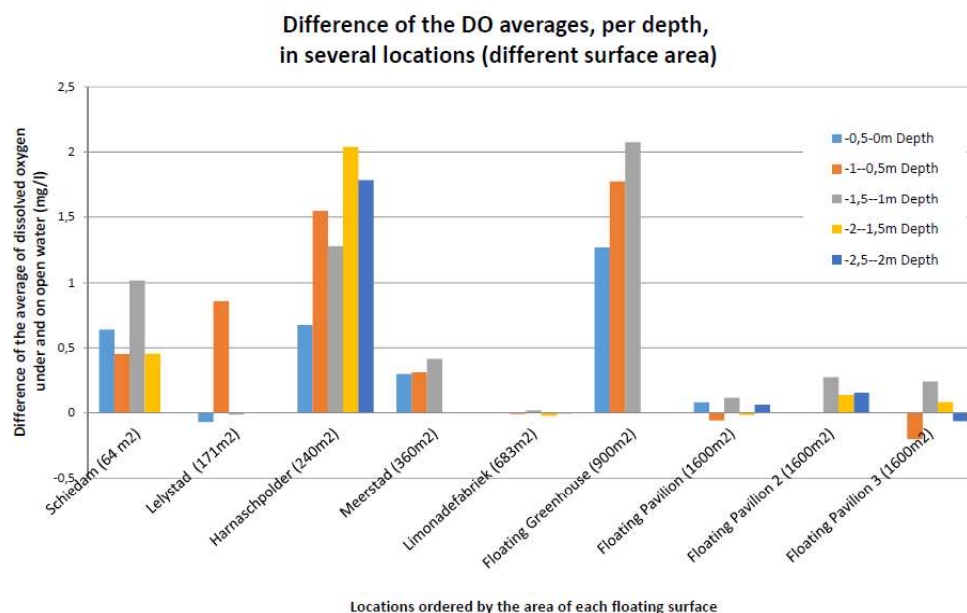


Figure 7 Differences in dissolved oxygen concentration in different locations with multiple platform sizes, per depth interval.

Another factor that may contribute to changes in the availability of dissolved oxygen is the vegetation/benthic/bivalves ecosystem that is present under/nearby floating structures. The vegetation can produce dissolved oxygen due to photosynthesis, therefore influencing water quality under floating buildings. The underwater drones, equipped with cameras, allowed to capture underwater footage of the aquatic ecosystems in the vicinity of the floating structures (Figure 8). Although some of the visited locations had high water turbidity, in some locations lively ecosystems were visible, with bivalves hanging from the structures, as well fish (different sizes, inclusively underneath the floating structure) and aquatic plants (mostly around the structures).



Figure 8 Example of underwater images collected by underwater drones: a) macrophytes/vegetation (*left*), b) fish under platform (*center*), c) mussels attached to wall (*right*)

4 Conclusion

Results of this study indicate that there are detectable variations in concentrations of water quality parameters between open water and under/near floating structures, but they were consistently low. For instance, in most of the cases, dissolved oxygen did not vary more than 1-2mg/l between each position, and the minimum values detected are above the required for a healthy habitat. Regarding the nitrate and ammonium measurements (not available in all locations), the measured concentrations were within the expected total nitrogen concentration and the differences were also small (also lower than 1-2 mg/l).

The collected datasets in each location corresponded to a specific moment in time (few hours or measurements), and therefore it did not take into consideration the daily/seasonal variability of water quality. Additionally, no physical/hydrodynamic characteristics of the water bodies was analysed. Continuous water quality data collection (for several days or months), and additional knowledge about the characteristics water body where the floating structure is built (e.g. currents, flow velocities) are important for follow-up studies. Considering the complexity of the interactions between water quality parameters and the influence of the surrounding environment it is recommended to continue and to improve the monitoring campaign (e.g. include new parameters).

During this research, it became clear that the characteristics of water body is a decisive factor for the extent of impact of water quality structures on water quality, as currents and mixing capacity highly influence the renewal rate of water under the structures. This aspect varied considerably from location to location, as the floating structures were located in different water bodies such as ponds, streams, or lakes. For this reason, it was not possible to establish clear relationships between water quality and characteristics such as the area of the structure, coverage of the water body, or the available space below the house.

Besides physicochemical water quality measurements, the underwater footage allowed to observe and to demonstrate the presence of fish under and nearby the floating structures, which is also an indicator for the health of the water system. A substantial amount of fish and organisms were found attached to this kind of structure, creating a new habitat where otherwise there wouldn't be much bio-diversity.

The research was limited to the available small scale floating structures that currently exist in the Netherlands. Despite the detected variations in water quality parameters, these structures do not seem to have a significant negative impact in the water quality, and may even be regarded as opportunities for building with nature, considering all the new habitat that was unveiled with the underwater images. However, this might be different in the future if the scale and number of projects increase. In order to ensure that bigger scale projects continue not to have an adverse impact in the environment, further research is necessary to infer about recommendations and best practices for the development of larger scale floating urbanization. Aspects such as determining the acceptable platform density ranges, acceptable coverage ratio of the water body, how to minimize the blockage of sunlight (e.g. best positioning of constructions), evaluation of the best materials to use in these structures (ecological/chemical point of view), or how to improve water movement/circulation (prevent water to remain for long periods in the same place) should be taking into future plans and design for the floating development. By integrating floating wetlands or other designs/solutions that enhance the development of underwater habitats (Figure 9), floating projects could potentially improve water quality and biodiversity, be an opportunity for the implementation of green solutions, and contribute to enhance the connection of the cities with the nature, and in particular, the water.



Figure 9 Examples of floating green solutions (floating wetlands and gardens) that can potentially be combined with floating constructions for minimising undesired impacts of floating platforms and stimulating ecosystems and biodiversity

The collected data, information and videos from the several studied locations around The Netherlands are available in an online tool (www.climatescan.org).

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